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Research paper

Evaluation of sorghum hybrids for biomass production in central Italy

Euro Pannacci*, Simone Bartolini

Department of Agricultural, Food and Environmental Sciences, University of Perugia, Borgo XX Giugno, 74-06121, Perugia, Italy

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ABSTRACT

Two field experiments were carried out in 2005 and 2006 in central Italy in order to evaluate the biomass production and quality in eight sorghum hybrids, to define their biomass partitioning among leaves, panicles and stems and to identify which were the most adapted at early harvest. Sorghum showed a high potential in terms of biomass production in central Italy, with biomass dry yield of 25 t ha^{-1} in average, adopting low input in terms of irrigation and fertilization. The most productive hybrids were H133 (26.3 t ha^{-1}) and H952 (25.9 t ha^{-1}) among the biomass hybrids and SS506 (27.3 t ha^{-1}) among the forage hybrids. The trends of dry weight and moisture content of biomass during the different hybrids growth cycles allowed to estimate the biomass production of each hybrids, hypothesizing an early harvest at 20 August with in-field drying of biomass. Early harvest reduced dry weight of biomass from 4.6% to 21.7%, depending of hybrids; SS506 and H128 showed to be the most adapted at early harvest. HHV and LHV of biomass showed average values higher in biomass hybrids (18.4 and 17.5 MJ kg^{-1} d.m.) than in forage hybrids (17.7 and 16.8 MJ kg^{-1} d.m.); while, ash content average values were lower in biomass hybrids (6.8% d.m.) than in forage hybrids (7.7% d.m.). The highest values of leaves + panicles partitioning in the forage hybrids increased ash content, reducing the quality of their biomass for thermal utilization; the biomass hybrids should be therefore preferable.

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1. Introduction

Sorghum (*Sorghum bicolor* L. Moench) is a widely adapted crop with potential for bioenergy production [1]. Bioenergy sorghum is also of interest due to its relatively low input requirements, drought tolerance, and ability to maintain high yields under a wide range of soil and environmental conditions [2]. Furthermore, an important characteristic of sorghum is that could be grown in crop rotations with food crops, allowing the use of common crop management practices and farm machineries [3]. In relation to the wide genetic variability of this species, sorghum is used to obtain the most disparate products: food, forage, paper pulping, plastics, sugar for bioethanol and biomass for energy use [4]. In fact, among the cultivated sorghums, bicolor sorghums represent types that have been selected not only for grain production but also for biomass, forage and sugar production [5]. In general the content of non-structural carbohydrates (sucrose, glucose, fructose and starch) is higher in sweet sorghum types than in forage or biomass ones. The biomass and forage types are predominantly composed by structural carbohydrates (hemicellulose, cellulose, and lignin) and their biomass can be used for combustion and 2nd generation biofuels [6]. However all types of sorghums produce lignocellulose that could serve as feedstock for second generation biofuels. Genotypes with a high cellulosic production potential are being developed, although sweet and forage/biomass sorghum types are not completely distinct between them as they share many common characteristics [7]. One of the most important characteristic of the lignocellulosic energy crops should be the highest biomass production with the lowest moisture content at harvest time. In fact, the high moisture content of the sorghum biomass at harvest (ca. 70%) poses problems for transportation and storage [6,8]. Sorghum is currently harvested using conventional forage equipment, and is typically stored either as silage or as dry bales [6,9]. In this latter case, the moisture content of dry bales needs to be less than 20% to reduce the risk of detrimental biological activity [6]. In-field drying is favourably used for biomass sorghum in Italy, thanks to the warm and dry conditions during the summer; although in this case an early harvest is required [10]. On the other hand, the optimal stage for harvesting to maximize the sorghum yield, in quantitative and qualitative terms, is around the soft dough stage of grain filling [6] that, however, can make difficult in-field drying of biomass due to the begin of autumn conditions. Some authors, using modelling,

* Corresponding author.
E-mail address: euro.pannacci@unipg.it (E. Pannacci).

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found that biomass yield of sweet sorghum can be estimated from leaf area index and stalk length for scheduling of harvest [11]. However, little is know about whether early harvest is advisable for biomass sorghum production and which hybrids can be more adapted in the Mediterranean areas. Furthermore, sorghum biomass yield and biomass partitioning to individual tissues types can be influenced by cultivar, varying the biomass quality for combustion, due to differences in mineral composition, especially in terms of ash content [12]. The objectives of the study, carried out under environmental conditions of central Italy, were to evaluate: (1) the biomass production and biomass quality in eight sorghum hybrids; (2) the curves of biomass growth in the sorghum hybrids in order to identify which were the most adapted at early harvest; (3) to evaluate the biomass partitioning among leaves, panicles and stems in the different hybrids.

2. Materials and methods

Two field experiments were carried out in 2005 and 2006 in central Italy (42°57′N, 12°22′E, 165 m a.s.l.) on a clay-loam soil (22% sand, 35% clay and 43% silt, 1.5% organic matter). Eight sorghum hybrids were selected (Table 1).

Experimental design was always a randomized block with four replicates and plot size of 32 m^2 (4 m width). Each plot was established from eight rows, six central rows for measurements and two border rows on the perimeter of each plots to reduce potential border effects. The main agronomic practices are shown in Table 2. The trials were carried out in accordance with good ordinary practices, as concerns soil tillage, seedbed preparation and weed control [13,14], adopting low input in terms of irrigation and fertilization.

2.1. Measurements and statistical analysis

The plants height of sorghum was measured at the height of the last leaf on 30 plants per plot at 75 DAE (days after emergence) and at 116 DAE, in 2005 and 2006, respectively. Flowering time was the date (reported as DAE) to which 50% of plants in each plot were flowered and was used as parameter to evaluate the different degree of precocity among hybrids. The fresh and dry weight of biomass of sorghum and the moisture content were determined during the growth season (only in 2006, four sampling at 43, 64, 93, and 116 DAE) and at the harvesting time (141 DAE in 2005 and 127 DAE in 2006). During the growth season in 2006, at each sampling, 18 plants per plot were cut at the ground level, linearly from the six central rows (3 plants for each row), removed manually and weighed. A sample from each plot (20% of total fresh biomass) was taken, collecting three different parts of the plants (basal, central and apical). The samples were then weighed fresh, oven dried at 105 °C to a constant weight in order to assess moisture content, dry weight of biomass and then an equivalent yield (t ha^{-1}) for each plot. At harvesting time, in each plot, the plants from the six rows in the central part of plot (21 m^{-2} in 2005 and 12 m^{-2} in 2006) were cut, weighted and sampled as above mentioned in order to evaluate the moisture content and dry weight of biomass. Furthermore, in 2006, the biomass of sorghum was subdivided in stems, leaves and panicles and their weight was evaluated. In 2006, a sample of total dry biomass for each hybrid was obtained collecting a sub-sample of biomass (taking stems, leaves and panicles at the quantity of 10% of their respective weight) from each pot and then adding the replication, for a total of six samples. These samples were analysed to determine lower and higher heating values (LHV and HHV) and ash content of biomass, using, respectively, a calorimeter (AC-350 Leco) and a thermo-gravimetrical analyzer (TGA-701 Leco).

The data of dry weight of biomass of sorghum collected during the growth season were subjected to a non-linear regression analyses by using the model proposed by Refs. [15,16]:

$$\log_e W = ae^{-be^{-cT}}, \quad (1)$$

where, W is the dry weight of biomass (t ha^{-1}), a, b, c are the parameters of the model and T is the time (expressed as DAE).

The data of the moisture content of biomass of sorghum collected during the growth season were subjected to a linear regression analyses by using the model:

$$y = -ax + b, \quad (2)$$

where x is the time (expressed as DAE) and y is the moisture content (expressed as % of fresh weight).

The data of dry weight and moisture content of biomass, were extrapolated from the nonlinear and linear regressions, respectively, at the 20 August (91 DAE); this last date was chosen as early harvest. The estimated values at 91 DAE (early harvest) were compared with the corresponding data obtained at harvesting time (25 September, 127 DAE) and the variations among them were analysed in order to evaluate differences among hybrids in terms of dry weight and moisture content of biomass.

All data (except HHV, LHV and ash content, because without replications) were subjected to ANOVA using the EXCEL® Add-in macro DSAASTAT [17] and treatments means were separated using Fisher's protected LSD at P = 0.05 level.

Meteorological data (daily maximum and minimum temperature and rainfall) were collected from a nearby station. The average decade of daily values were calculated and compared with multi-annual average values (from 1921) (Fig. 1).

3. Results and discussion

In 2005, the forage hybrids showed higher precocity than biomass hybrids, anticipating the flowering time of 25 days in average (Table 3). The extended duration of the growth cycle for the biomass hybrids, makes that these grow greater than forage hybrids, as shown by the values of the plants height at 75 DAE (Days After Emergence) (Table 3). Also the biomass production of biomass hybrids at 141 DAE was higher than forage hybrids. In particular, dry weight of biomass was, in average, 21.6 t ha^{-1} for the biomass sorghum hybrids (H133 and H952) and 14.5 t ha^{-1} for the forage sorghum hybrids (Speedfeed and Grazer N) (Table 3). The moisture content of biomass didn't show significant differences among the hybrids with values than ranged from 65% to 67% (Table 3). Due to the low biomass production, Speedfeed and Grazer N were substituted in 2006 with other forage hybrids (Hikane II, SS405 and SS506) that seemed to be more productive.

Table 1
Sorghum hybrids selected for the two field experiments in 2005 and 2006.

Sorghum hybrids	Years	
	2005	2006
Biomass		
H133	✓	✓
H952	✓	✓
H128	–	✓
Forage		
Speedfeed	✓	–
Grazer N	✓	–
Hikane II	–	✓
SS405	–	✓
SS506	–	✓

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